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MEMORANDUM REPORT  
NO. 1652

HYPERVELOCITY IMPACT: DEPENDENCE OF  
CRATER DIMENSIONS ON IMPACT VELOCITY

By John H. Klineke, Jr.

MAY 1965

U. S. ARMY MATERIEL COMMAND  
BALLISTIC RESEARCH LABORATORIES  
ABERDEEN PROVING GROUND, MARYLAND

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BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 1652

MAY 1965

HYPERVELOCITY IMPACT:  
DEPENDENCE OF CRATER DIMENSIONS ON IMPACT VELOCITY

John H. Kineke, Jr.

Terminal Ballistics Laboratory

This work was partially supported by ARPA, under  
ARPA Order No. 71.

RDT & E Project No. 1P014501A33E

ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 1652

JHKineke/cr  
Aberdeen Proving Ground, Md  
May 1965

HYPERVELOCITY IMPACT:  
DEPENDENCE OF CRATER DIMENSIONS ON IMPACT VELOCITY

ABSTRACT

Craters in copper and lead, produced by hypervelocity impact, have been measured and the dimensions correlated with impact velocity. The results indicate that craters scale with about the 1.7 power of velocity, in agreement with computer physics results based upon hydrodynamic calculations.

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## INTRODUCTION

Numerous empirical correlations of crater dimensions with projectile impact velocity have been presented by various investigators. In general, these correlations can be classified in either of the following two groups:

1. Crater linear dimensions varied with the one-third power of the projectile velocity and crater volume with the first power of velocity, leading to a statement that craters scaled with the projectile momentum.

2. Crater linear dimensions varied with the two-thirds power of the projectile velocity and crater volume with the square of the velocity, leading to a statement that craters scaled with projectile energy.

Actually, it has long been recognized that both points of view represent oversimplifications and are useful only for purposes of interpolation and modest extrapolation. It was at first assumed that the dependence of crater dimensions on impact velocity could not be arrived at without a complete treatment of the crater formation process, including the later, strength-dependent portion. This supposition is too restrictive, however. Certainly, the size of a given crater cannot be computed by considering only the hydrodynamic portion of the process, without treating strength effects. Yet, certain trends can be discerned just from performing computations in the regime where no doubt exists as to the validity of the hydrodynamic assumption. These considerations led Walsh and co-workers<sup>1\*</sup> to advance the concept of late-stage hydrodynamic equivalence. Simply stated, the gross features, such as size and shape of the final craters from two different impacts will be the same if the gross transient features of the impacts are the same at a time sufficiently short after impact so that pressures in the target are large compared to the strength of the material. That is, if the hydrodynamic solutions of the flows resulting from the impacts are essentially the

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\*Superscript numbers denote references found on page 15.



same at late times within the hydrodynamic phase, then the untreated post-hydrodynamic phases of the interactions will be the same. This leads to a scaling of craters dependent only upon the mass and velocity of the projectiles which produced them, expressly stated by the relation:

$$m_1 v_1^{3\alpha} = m_2 v_2^{3\alpha}.$$

Based upon consideration of momentum and density distributions in the target Walsh and co-workers have computed  $3\alpha$  to be  $1.74 \pm 0.06$ , from both particle-in-cell and continuous Eulerian formulations of two-dimensional axisymmetric problems.

Observations of final crater dimensions over a substantial range of projectile velocity can be used to determine  $3\alpha$  experimentally. This report describes this determination, summarizing terminal crater observations made at the BRL in copper and lead.

#### EXPERIMENTAL OBSERVATIONS

Chunky projectiles of steel, aluminum, and titanium, were accelerated from several types of explosive devices described elsewhere. These include the BRL Air-Cavity Charge<sup>2</sup>, the BRL Inhibited-Jet Charge<sup>3</sup>, and the BRL Micro-Particle Accelerator<sup>4</sup>. The projectiles struck essentially semi-infinite targets of lead and copper at velocities up to 12 km/sec., at normal incidence.

Measurements of crater dimensions with respect to the level of the undisturbed surface were made. Crater diameters, normalized by dividing by the one-third power of projectile mass, and crater volumes, normalized by dividing by projectile mass, are plotted versus projectile velocity in Figures 1-4.

These data were then fitted to functions of the form:

$$y = a + b v_p^c$$

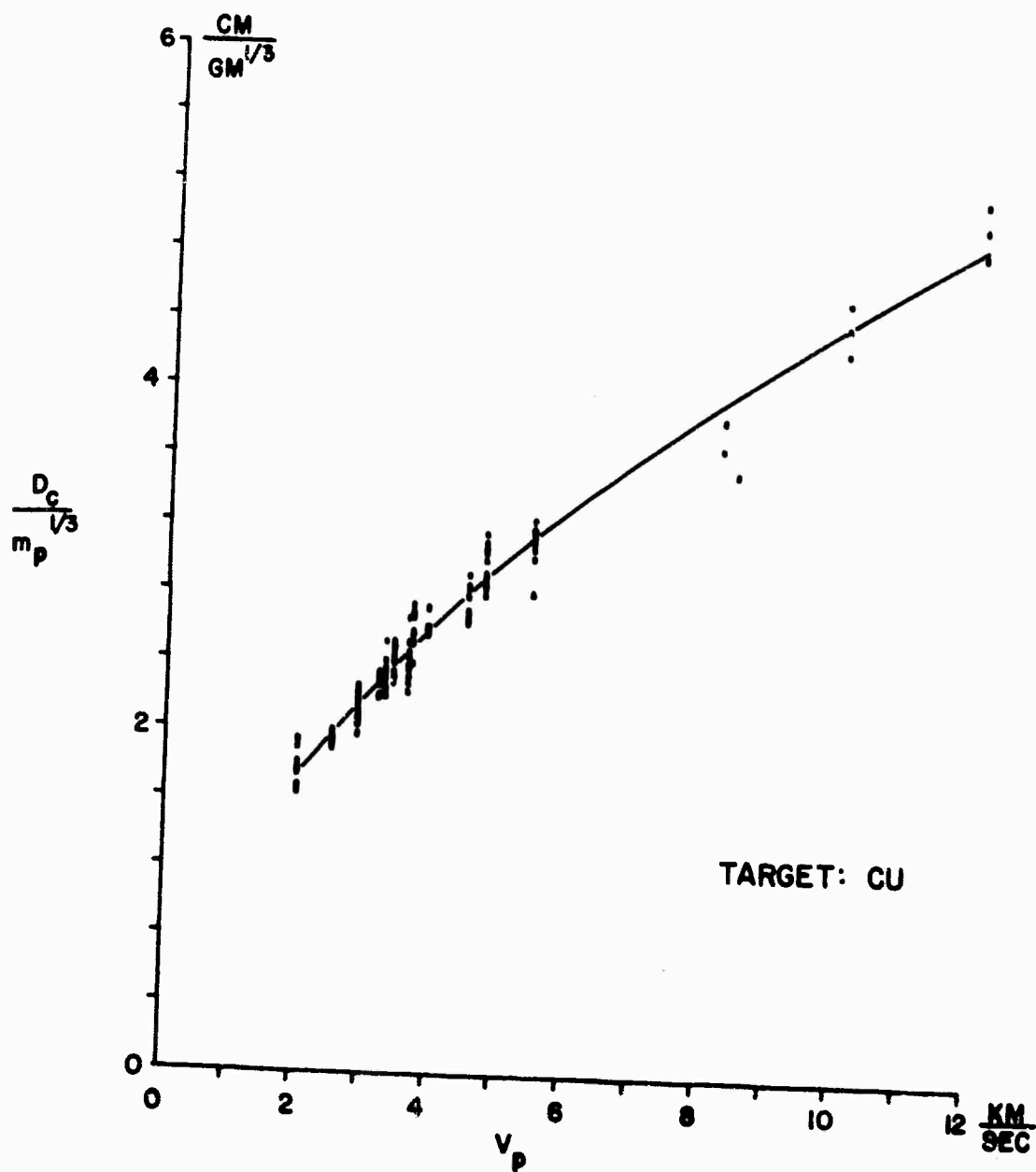
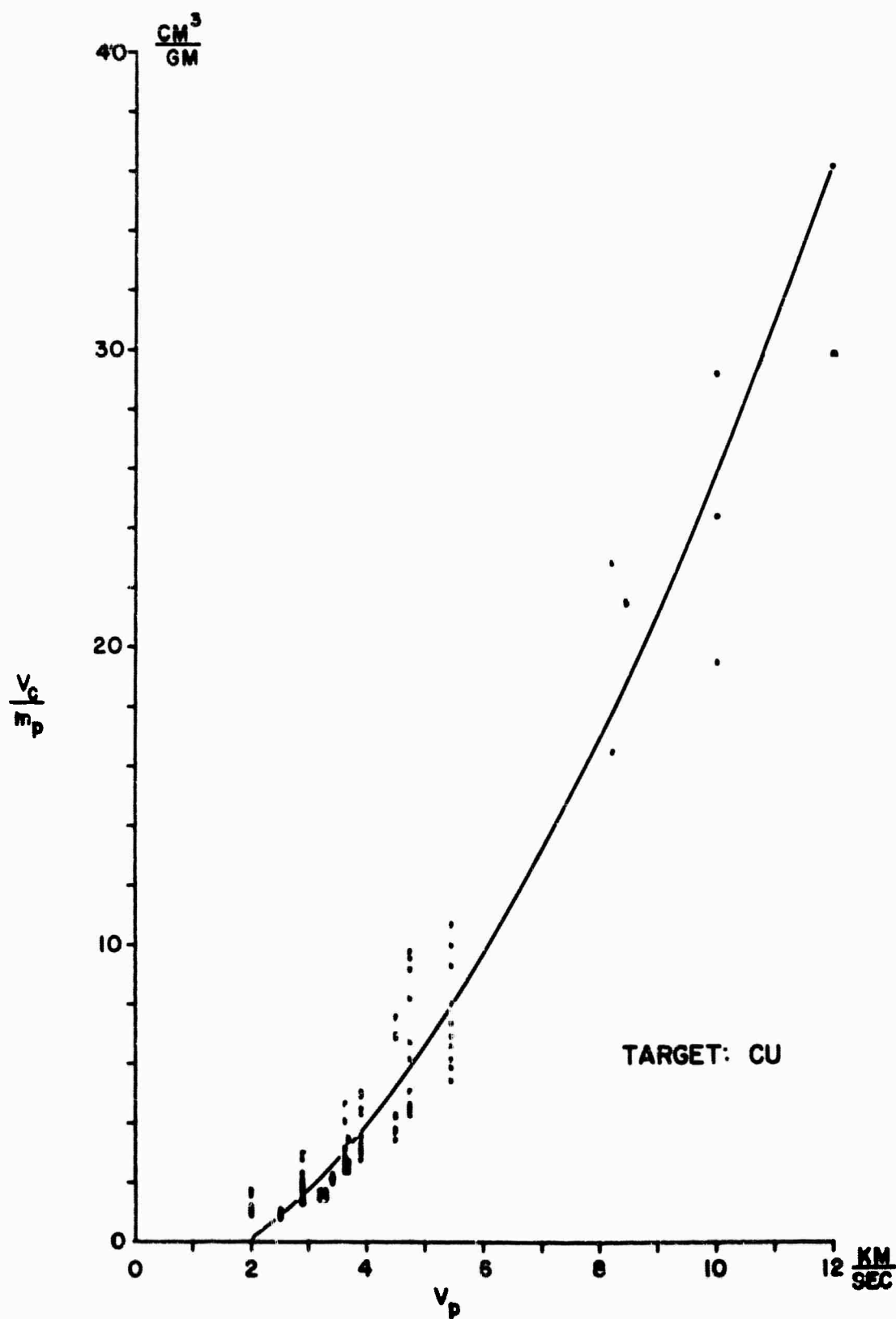
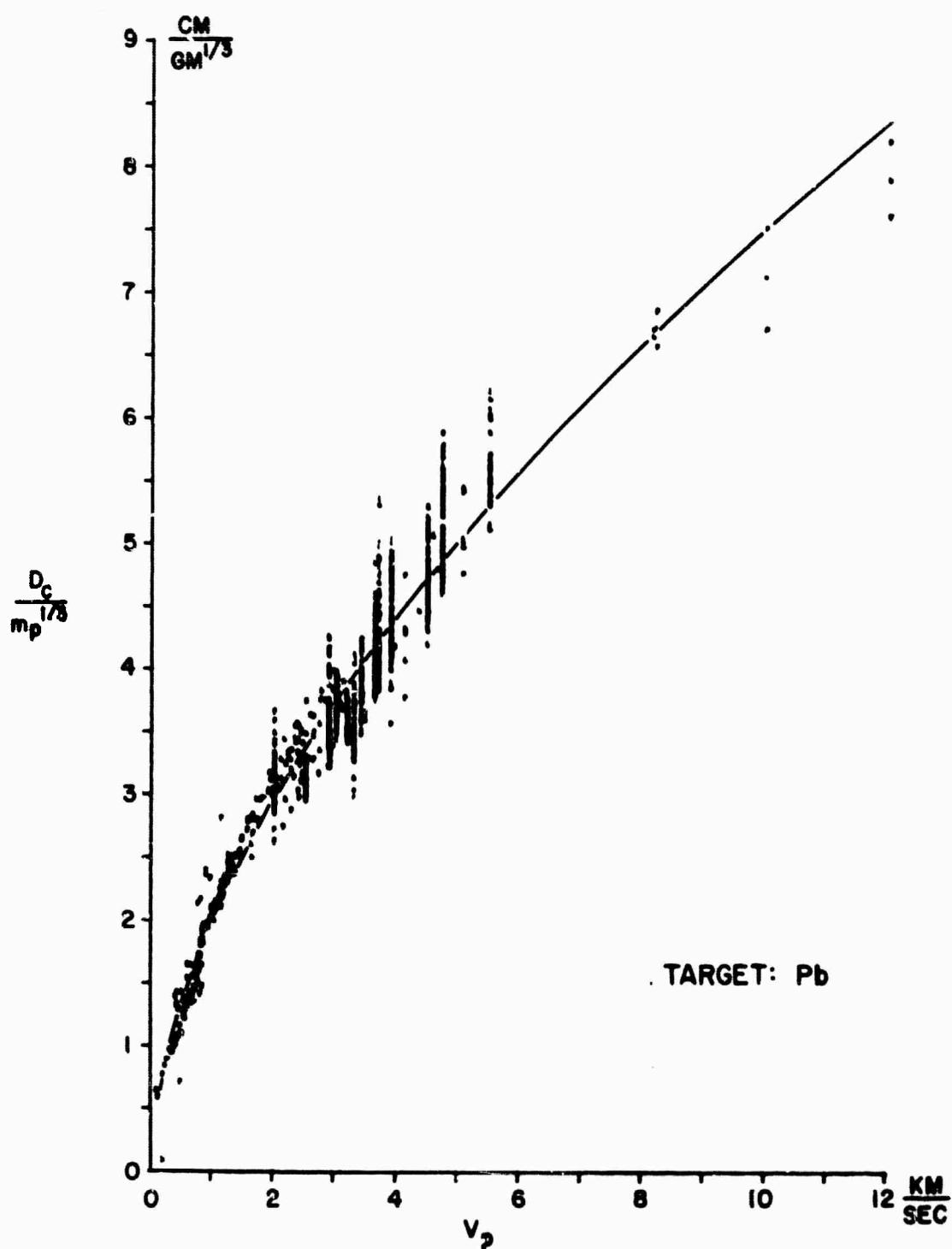


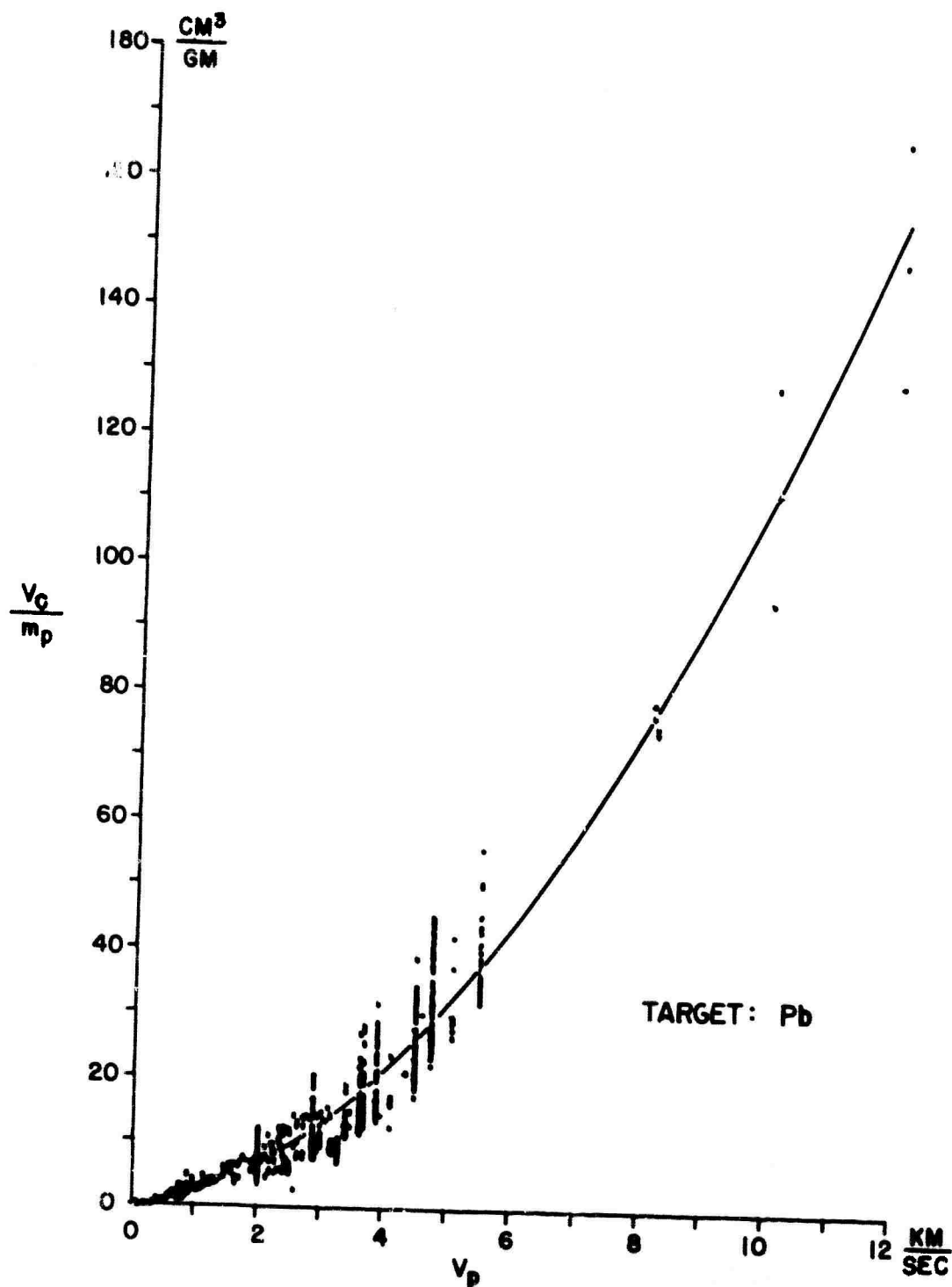
FIGURE 1 Normalized crater diameter data for normal impacts in copper targets, as a function of impact velocity. The line drawn through the data corresponds to the 0.55 power of the impact velocity.



**FIGURE 2** Normalized crater volume data for normal impacts in copper targets, as a function of impact velocity. The line drawn through the data corresponds to the 1.77 power of the impact velocity.



**FIGURE 3** Normalized crater diameter data for normal impacts in lead targets, as a function of impact velocity. The line drawn through the data corresponds to the 0.58 power of the impact velocity.



**FIGURE 4** Normalized crater volume data for normal impacts in lead targets, as a function of impact velocity. The line drawn through the data corresponds to the 1.79 power of the impact velocity.

by applying a differential correction technique<sup>5</sup> to the parameters a, b, and c. Thus, in order to determine the differential corrections da, db, and dc, a least square fit was performed on the function

$$dy = da + v_p^c db + b v_p^c \ln v_p dc$$

The differential corrections so determined were then applied to the original estimates of a, b, and c and the process repeated as many times as necessary for convergence to take place. Usually, the parameters converged, to five significant figures, in five iterations.

In performing the fitting operations, velocities have been expressed in kilometers/second, masses in gram, diameters in centimeters and volumes in cubic centimeters.

## RESULTS

The results of the analysis described above are summarized in Table I. For copper targets, data from impacts at velocities between 2 and 12 km/sec have been used. For lead targets data between 0.05 and 12 km/sec have been used.

TABLE I

		a	$\sigma_a$	b	$\sigma_b$	c	$\sigma_c$	$\sigma_r$
Cu	$\frac{D_c}{m_p^{1/3}}$	-0.165	0.311	1.297	0.247	0.547	0.055	0.118
	$\frac{V_c}{m_p}$	-1.434	0.505	0.464	0.106	1.767	0.091	1.532
<hr/>								
Pb	$\frac{D_c}{m_p^{1/3}}$	-0.009	0.105	1.990	0.098	0.580	0.018	0.279
	$\frac{V_c}{m_p}$	-0.238	0.376	1.796	0.097	1.791	0.025	4.544

These fits are plotted in Figures 1-4.

For the diameter fits,  $c$  represents a determination of  $\alpha$ , and for the volume fits, a determination of  $3\alpha$ . Standard deviations are shown for all parameters, together with the standard deviation of the residuals. The intercept  $a$ , in every case, is not sufficiently far from the origin to be significant.

#### CONCLUSION

The experimental values of  $\alpha$  ( $0.547 \pm 0.055$  and  $0.580 \pm 0.018$ ) and  $3\alpha$  ( $1.767 \pm 0.091$  and  $1.791 \pm 0.025$ ) agree quite well with the computer physics results of  $0.58 \pm 0.02$  and  $1.74 \pm 0.06$ . Thus, it can be concluded that the terminal crater data do not contradict the hypothesis that  $\alpha = \pm 0.58$  and  $3\alpha = \pm 1.74$ .

#### ACKNOWLEDGEMENTS

The author wishes to thank Mr. Lee S. Holloway and Mr. E. T. Roecker, both of the Terminal Ballistics Laboratory, BRL; the former for performing the impact experiments, and the latter for providing the computer program used in this investigation.

JOHN H. KINEKE, JR.

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Unclassified

Security Classification

**DOCUMENT CONTROL DATA - R&D**

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

**1 ORIGINATING ACTIVITY (Corporate author)**

Ballistic Research Laboratories  
Aberdeen Proving Ground, Maryland

**2a REPORT SECURITY CLASSIFICATION**

Unclassified

**2b GROUP**

**3 REPORT TITLE**

HYPERVELOCITY IMPACT: DEPENDENCE OF CRATER DIMENSIONS ON IMPACT VELOCITY

**4 DESCRIPTIVE NOTES (Type of report and inclusive dates)**

**5 AUTHOR(S) (Last name, first name, initial)**

Kineke, John H., Jr.

**6 REPORT DATE**

May 1965

**7a. TOTAL NO. OF PAGES**

19

**7b. NO. OF REFS**

5

**8a. CONTRACT OR GRANT NO.**

b. PROJECT NO. 1P014501A33E

c.

d.

**9a. ORIGINATOR'S REPORT NUMBER(S)**

Memorandum Report No. 1652

**9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)**

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This work was partially supported by  
Advanced Research Projects Agency, under  
ARPA Order No. 71

**13 ABSTRACT**

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KEY WORDS	LINK A		LINK B		LINK C	
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